DEVELOPMENT OF BEST PRACTICES FOR NUCLEAR POWER PLANTS

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Abstract

Motivation of this research is due to the progression of construction methods since the last nuclear power plant construction boom. How things were constructed in the past in comparison to how things are constructed in the present promote many risks to owners and contractors that compromise successful completion of projects. Benchmarking and lessons learned from past and current nuclear construction projects must be utilized in mitigating risks in order to progress forward with new deployment of nuclear power plants. This study presents understanding of the increasing demand for electricity and the need of nuclear power generated electricity. Further information provides an in depth look at the root causes of nuclear project problems and/or issues, correlating to cost and schedule overruns, which in extreme cases have been the sources for nuclear project shutdowns affecting the construction industry as a whole. The research offered reiterates known causes faced during nuclear project construction phases. In this study, nine nuclear power plants and one U.S. fuel enrichment facility were examined to help identify root causes and develop best practices that can be implemented in nuclear power plant construction projects.

1. Introduction

Since the demand for electricity is projected to increase 45 percent by 2030, the U.S. has called for a nuclear renaissance. It calls for cleaner, less fuel consumption, and waste electricity generation. Nuclear energy is a greenhouse friendly industry. It admits no emissions that hurt the atmosphere. A total of 23 new nuclear power plant applications are expected between 2007 through 2010. It has been over 25 years in the United States since a new nuclear plant has been ordered. Construction and technology during that time was different. In addition, reactor designs were not certified by the Nuclear Regulatory Commission (NRC) before being constructed. It may have been effective for some companies and organizations, but overall it costs the industry time and money.

1.1. Objectives

The purpose of this research is to identify problems and issues related to constructing a nuclear power plant. Problems and issues cannot be avoided during phases of construction. They are inevitable in every construction project, but are unique to nuclear construction. It is difficult to research and identify specific problems and issues associated with nuclear construction since most, if not all, are kept secret from the general public.

Research for this paper was conducted with the following objectives:
1. Research past and present international and domestic nuclear power plant construction projects;
2. Identify problems and issues related to each project;
3. Determine the root cause of each problem or issue;
4. Develop a best practice for each problem or issue; and
5. Propose implementation techniques and tools to help mitigate problems or issues associated with constructing a nuclear power plant.

Numerous past nuclear projects in the U.S. were over budget and schedule, in many cases causing the entire project to shut down, which cost the owner and contractor billions of U.S. dollars. In retrospect, these issues possibly could have been avoided. Perhaps by researching and identifying key problems and issues, determining causes of the problems and issues, and implementing techniques, tools, and/or processes that would help owners and contractors aid in the reduction of schedule and cost overrun during project duration.

1.2. Research Methodology

In this study, the majority of nuclear power plant construction problems and issues were collected from the Institute of Nuclear Power Operations (INPO) and South Texas Project Nuclear Operating Company (STPNOC) located near Wadsworth, Texas in Matagorda County. Established by the nuclear power industry in December 1979, INPO is a not-for-profit organization. Their mission is to promote excellence of safety and reliability in the operation of nuclear generating plants. The organization evaluates nuclear plants around the nation and releases the results to other plants to help improve their operations to ensure safety. Evaluated plants include domestic and international plants conducted in different environments around the world past to current.

STPNOC currently operates 2 units and a planned 2 additional units are scheduled to be constructed at the site, Units 3 and 4. Documentation provided by STPNOC cover nuclear projects of the same ABWR design as future Units 3 and 4. Further significant information was obtained from U.S. government organizations such as the NRC and Nuclear Energy Institute (NEI). In order to present up-to-date information, INPO and STPNOC reports utilized in this research were conducted between years 2006 to 2008. Total project cost and schedule were not a factor in determining what vital information should be used.

From documentation collected by several companies and organizations, including ones previously stated, this paper will explore the nuclear option. It will discuss the numerous risks and lessons learned from the past to current nuclear power construction projects. In addition, discussion of best practices that may be applied to mitigate those risks will be explored. Best practices are developed from existing Construction Industry Institute (CII) documented best practices as well as ones documented by the nuclear industry. Figure 1 shows the detail of the research methodology.

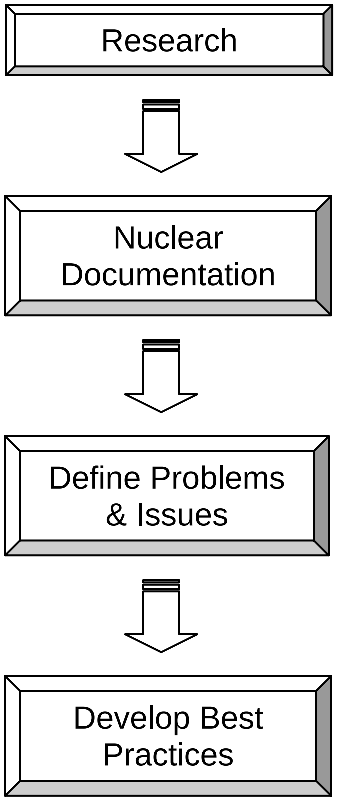

Figure 1 Research Methodology

2. Background

The majority of nuclear power plants in the U.S. today were built between 1965 and 1985. Commercial nuclear energy was new, and the federal regulatory process evolved along with the new industry. The NRC issued a construction permit based on a preliminary design, and it did not resolve safety issues until the plant was essentially complete. Now, more than 30 new U.S. reactors are in varying stages of planning, and that number is expected to grow as the industry and the NRC gain experience with the new licensing process [3][4].

Nuclear power plants use fuel to heat water into high-pressure steam that spins the fan blades of turbines, which turn generators that produce electricity. In a fossil fuel plant coal, natural gas, or oil is burned to produce heat. In a nuclear power plant, enriched uranium is used as the nuclear fuel component. Nuclear fission occurs, producing heat. The heat is then transferred to water, producing steam. The steam is used to turn the turbine. The turbine is connected to a generator that produces electricity. The electricity is then sent out over the electrical grid, which eventually delivers the product to the end user. Nuclear power is produced at a much lower cost and emits less pollution than fossil fuel plants. On the other hand, constructing a new nuclear power plant at present time is unlike the process when they were built over 25 years ago. The designing, construction, and operating of a nuclear plant is a long, costly and complex process creating problems and issues arising from the multifaceted phases of construction. The new process requires a combined operating license to be submitted, which may take up to several years to be reviewed and approved by the NRC, followed by procurement of long lead-time items, and finally beginning of construction.

2.1. Nuclear Power Plant Issues

It has become very obvious that the nuclear option is becoming a reality in the U.S.. Several utilities have applied for the Combined Operating License with the NRC and many projects are forming across the nation. The nation will need hundreds of new power plants from a diverse portfolio of fuel sources to supply electricity for a thriving economy and high standard of living [3][4]. By maintaining the current fuel mix and building new base load capacity to meet the project demand, the increase in electricity demand would require:

- 50 nuclear plants (1000 MW)
- 261 coal plants (600 MW)
- 279 natural gas plants (400 MW)
- 93 renewable (100 MW)

However, the construction industry must proceed with caution, because there were significant lessons learned during the last wave of nuclear construction. Numerous problems and issues arose ranging from reactor designs to start-up and operations.

2.2. CII Best Practices

CII was established in October 1983 to help develop construction industry standards through extensive research of construction industry. CII membership has grown steadily since it was formed, which includes a three-way partnership between contractors, owners, and academia. Each contributes a certain percentage of knowledge for research development. The membership has included companies from all industry sectors with the exception of residential housing construction. The heavy industrial sector has had a greater representation in the membership than has light industrial/general buildings and infrastructure, with members from the petrochemical, oil and gas, chemical, power, and pulp and paper industries being involved. One consequence is that more of the projects used as resources in CII research have come from the heavy industrial sector [2].

As can be seen from Figure 2, information topics are first established. Information topics are research findings that are created from construction industry subjects brought about from members of CII. These have not been developed into processes or methods, but are important to the industry. Once information is developed into a process or method then it possibly may evolve into a practice. A practice defined by CII is, “a process or method that may become a best practice, but has not been sufficiently proven" [1]. After a practice is sufficiently proven through extensive industry use or validation it develops into a best practice. A best practice is a process or method that if implemented and exercised correctly can enhance or improve project performance.

Each best practice is grouped into a knowledge area defined by CII. Currently, there are fourteen CII knowledge areas. The knowledge areas are further divided into project phases. CII has developed best practices establishing the idea that construction research can have an impact on the construction industry. These best practices are for use in the construction industry as a whole and have not been specifically developed by CII for use in the nuclear construction industry. Even though nuclear construction is unique in its own aspects, industry best practices can still be applied to maximize effectiveness and efficiency throughout a project life cycle.

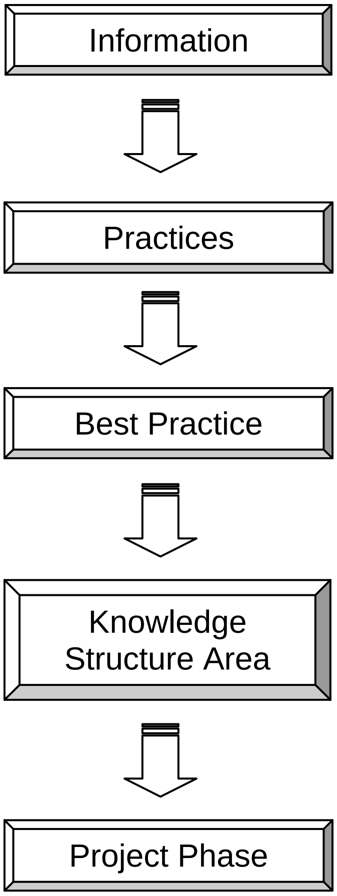

Figure 2 CII Methodology

In addition, each project is unique and should be treated as such. CII has developed and documented through research best practices to support and improve successful project implementation. Best practices can be described in part with CII's mission statement: "To improve the safety, quality, schedule, and cost effectiveness of the capital investment process through research and implementation support for the purpose of providing a competitive advantage to its members in the global marketplace" [1].

3. Case Studies

Nuclear power plants use enriched uranium as fuel for nuclear reactors to produce a controlled nuclear reaction. When mined, uranium is not ready for use as a fuel. It consists of different weights of atoms, which nuclear power plant reactors require a higher concentration of uranium.

3.1. Project 1: Louisiana Energy Services National Enrichment Facility

Louisiana Energy Services (LES) has made significant progress towards becoming the first U.S. centrifuge uranium enrichment plant. LES partnership is currently owned entirely by Urenco. Exelon, Duke Power, and Entergy were previously partners in LES but dropped out of the partnership following the issuance of the license to LES to construct and operate a uranium enrichment facility. LES intends to use Urenco's sixth generation gas centrifuge technology that is being used in Europe. Urenco has a capacity of about 20 percent of the world's enrichment market [5][6].

In 2003, LES submitted a license application and environmental report to the NRC to construct a uranium enrichment plant. The plant is currently under construction and projected production is to start in 2009.

3.2. Project 2: Restart of Browns Ferry Unit 1

The Tennessee Valley Authority (TVA) is the nation's largest public power provider. TVA owns and operates a mix of power systems that power the Tennessee Valley. The power systems mix consists of three nuclear (Browns Ferry, near Athens, Alabama; Sequoyah, in Soddy-Daisy, Tennessee, and Watts Bar, near Spring City, Tennessee), 11 fossil, 29 hydroelectric, six combustion-turbine, and one pumped-storage plant. The three nuclear power plants together provide enough electricity to power over three million homes in the Tennessee Valley.

Major construction began on Browns Ferry Nuclear Power Plant in 1967 and was completed in 1977. The nuclear plant consists of three nuclear generating units, which all three are General Electric boiling water reactors (BWRs). The generating capacity of all three reactors is 3,440 megawatts. Unit 1 began commercial operation in 1974 and has been shut down since 1985. Originally, unit 1 was shut down in 1975 due to extensive damage to the unit caused by a fire that was initiated by an employee. In 1985 all three units were shut down for operational and management issues. Units 2 and 3 came back on line in 1991 and 1995.

The TVA Board approved the restart of Unit 1 in 2002. After necessary upgrades and improvements, Unit 1 began 100% commercial operation in 2007 following NRC authorization.

3.3. Project 3: Shimane 3, Tomari 3, and Shin-Kori 1 & 2 Nuclear Power Plants

Chugoku Electric Power Company in Japan owns 12 thermal, 97 hydroelectric, and one nuclear power stations. The company's main business is generation, transmission, and distribution of electric power. Shimane Nuclear Power Plant is the sole nuclear power station owned and operated by Chugoku Electric. Commercial operation began for Unit 1 in 1975 and Unit 2 in 1989. Units 1 and 2 are Boiling Water Reactor (BWR) designs. Unit 3 reactor is an ABWR of GE-Hitachi design, scheduled for startup in mid-2011.

Tomari 3 Nuclear Power Plant is owned by the Hokkaido Electric Power Company (HEPCO) and is located in Matsue, Japan. There are two Pressurized Water Reactor (PWR) designs operating at the site and a third PWR began construction in 2003. The third unit is planned for commercial operation in mid-2009 and has a projected total project cost of $2.5 Billion. All reactors are Mitsubishi Heavy Industries design.

3.4. Project 4: Civaux, Kashiwazaki-Kariwa, and Hamaoka 5 Nuclear Power Plants

France has 58 nuclear reactors operated by Electricité de France (EdF), which is one of Europe's energy leaders. Civaux Nuclear Power Plant is located in Civaux, France and is operated by EdF. Units 1 and 2 are European Pressurized Reactors (EPRs), which were ordered in 1991 and 1993, respectively. Both commenced commercial operation in 1999. Total project cost was estimated at $4.1 Billion.

Kashiwazaki-Kariwa Nuclear Power Plant currently operates seven nuclear reactors. The nuclear plant began operation in 1985 and all seven were operating commercially by 1997. Units 1-5 are BWR design and units 6 and 7 are ABWR design. It has become the largest nuclear power station in the world in generating capacity with seven reactors generating 8,212 MW. It is owned and operated by the Tokyo Electric Power Company (TEPCO), which is the largest nuclear operator in Japan with 17 operating nuclear reactors.

Hamaoka Nuclear Power Plant is managed by Chubu Electric Power Company and currently has five operating nuclear reactors. Units 1-4 are BWR design and the fifth operating unit is an ABWR design, the last of which completed construction in 2004.

3.5. Project 5: Lungmen and Kashiwazaki-Kariwa Nuclear Power Plants

Lungmen Nuclear Power Plant, also known as the Fourth Nuclear Power Project, is managed by Taiwan Power Company (TPC) and is located in Yenliao, Taiwan. Currently, there are two ABWR units on site that are behind construction schedule due to various delays, even though construction began in 1997. Units 1 and 2 are expected to come on-line in 2009 and 2010, respectively. This project is Taiwan Power Companies largest single investment in a building program.

3.6. Project 6: Olkiluoto 3 Nuclear Power Plant

Olkiluoto 3 Nuclear Power Plant is scheduled to be completed and go online in 2011. Unit 3 is an European Pressurized Reactor design (EPR). The nuclear plant is located in Olkiluoto, Finland and is owned by Teollisuuden Voima Oy (TVO). The nuclear project is being implemented and delivered by a consortium formed by AREVA NP and Siemens as a fixed price turn-key agreement. Table 2 shows the detail information of the projects.

Project ID	Project Name	Project Duration	Project Cost	Total Number of Units	Location
Project 1	Louisiana Energy Services National Enrichment Facility	~ 6 Years	~ $1.5 Billion	N/A	Near Eunice, New Mexico U.S.A.
Project 2	Browns Ferry Unit 1 Restart	5 Years	~ $1.8 Billion	3	Near Athens, Alabama U.S.A.
Project 3	Shimane 3 NPP	~ 6 Years	NA	3	Matsue, Japan
	Tomari 3 NPP	~ 6 Years		3	Tomari, Japan
	Shin-Kori 1 & 2 NPP	~ 4 Years		4	Busan, S. Korea
Project 4	Civaux NPP	~ 8 Years	~ $4.1 Billion	2	Civaux, France
	Kashiwazaki-Kariwa NPP	~ 17 Years	N/A	7	Kashiwazaki-Kariwa, Japan
	Hamaoka 5 NPP	5 Years	N/A	5	Shizuoka, Japan
Project 5	Lungmen NPP	~ 14 Years	~ $6.5 Billion	2	Yenliao, Taiwan
Project 6	Olkiluoto 3 NPP	~ 7 Years	~ $4.43 Billion	3	Olkiluoto Island, Western Finland

Table 2 Description of the Projects

4. Developing Best Practices

This study was limited to a select number of international and domestic nuclear plant projects, consisting of nine nuclear power plants and one U.S. centrifuge uranium enrichment plant. It would not be wise to apply the results of this study to the construction industry as a whole. In this document, each best practice was developed based on authentic needs of the nuclear construction industry, which were addressed and supported by acknowledged problems and/or issues related to constructing a nuclear plant. Implementing specific best practices based on a determined need or desired outcome may help assist in the reduction of future occurrences.

Table 3 is an attributed list of existing CII best practices developed in result of CII knowledge structure issues. First, column 1 details an assigned code for each knowledge structure. Second, Column 2 is existing CII knowledge structure issues that relate to nuclear construction projects and column 3 is an explanation of each knowledge structure. Column 4 suggests a best practice or best practices with the associated knowledge structure issue. References for each best practice are documented in column 5. Table 4 explains the developed best practices from project 1.

Code	Knowledge Structure	Description	Best Practice	Reference
A	Front End Planning	Programming, schematic design, and design development	A1. Pre-Project Planning A2. Alignment	A1.1 CII SP39-2 A2.1 CII IR113-3 A2.2 CII IR113-2
B	Design	Overall completion of plant design	B1. Constructability	B1.1 CII SD-85
C	Procurement	Vendors/suppliers with programs approved to provide quality components and services. Understanding the need for a "nuclear culture"	C1. Materials Management	C1.1 CII IR7-3 C1.2 CII RS130-1
D	Construction	Construction of domestic and international nuclear power plants. Domestic nuclear power plants have not been constructed in decades	D1. Lean Construction	D1.1 CII SD-65
E	Start Up and Operations	Organizational transition from construction to start up and operations	E1. Planning for Startup	E1.1 CII IR121-2
F	People	Workforce availability problems resulted from unavailability of craft workers, lack of specialized skills, and the loss of critical skills	F1. Attract and Maintain Skilled Workers F2. Management of Education and Training	F1.1 CII SP14-1 F1.2 CII RR135-11 F2.1 CII IR40-2 F2.2 CII RS40-1 F2.3 CII SP14-2
G	Organization	Assessment of the performance of the organization	G1. Team Building G2. Leader Selection	G1.1 CII IR105-2 G1.2 CII SD-87 G2.1 CII IR134-2 G2.2 CII SP12-2
H	Project Processes	Process of planning and controlling the performance or execution of the construction of a nuclear power plant	H1. Lessons Learned H2. Benchmarking and Metrics H3. Quality Management	H1.1 CII BMM97-1 H2.1 CII SP36-2 H3.1 CII SP31-1
I	Project Control	Ensuring that the project objectives are met by monitoring and measuring progress and taking corrective action when necessary	I1. Cost and Schedule Control	I1.1 CII RS41-1 I1.2 CII IR107-2
J	Contract Issues	Information showing that the constructor's proposed or completed work meets the technical intent of the design	J1. Disputes Prevention and Resolution	J1.1 CII RS23-1 J1.2 CII SD-95
K	Safety, Health, and Environment	Technical and organizational preconditions for the safe operation of a nuclear power plant	K1. Zero Accidents Techniques	K1.1 CII SP32-2
L	Information Management Technology Systems	Operation of computerized nuclear power plants create change in workforce roles, from one of primarily controlling to one of primarily interfacing and responding to computerized control systems	L1. Fully Integrated and Automated Project Processes	L1.1 CII RS125-1 L1.2 CII IR125-2

Table 3 Best Practice Mapping Process

Problem / Issue	Best Practice
Incomplete detailed design	Implement a constructibility program to ensure design optimization needed before starting construction.
Vendor coordination, cooperation, and productivity across the site, cross-tied among all contractors	Systematically reform relationships between owner, contractor, and supplier so that suppliers of strategic procurement items and/or systems can be included in the full process and thereby have a significant positive impact on the time, cost, and quality of the entire engineering and construction process, as well as on the life cycle performance of constructed facilities.
Vendors not understanding the need for a "nuclear culture"	Systematically reform relationships between owner, contractor, and supplier so that suppliers of strategic procurement items and/or systems can be included in the full process. Vendors need to be treated as if it had not worked at a nuclear plant.
Depending on contractors for procurement	Systematically reform relationships between owner, contractor, and supplier so that suppliers of strategic procurement items and/or systems can be included in the full process and thereby have a significant positive impact on the time, cost, and quality of the entire engineering and construction process, as well as on the life cycle performance of constructed facilities.
Vendor programs approved to provide quality level 1 components and services	Systematically reform relationships between owner, contractor, and supplier so that suppliers of strategic procurement items and/or systems can be included in the full process and thereby have a significant positive impact on the time, cost, and quality of the entire engineering and construction process, as well as on the life cycle performance of constructed facilities. Owner may have have to help suppliers comply, such as by writing programs for the suppliers.
International equipment conforming to U.S. standards	Systematically reform relationships between owner, contractor, and supplier so that suppliers of strategic procurement items and/or systems can be included in the full process and thereby have a significant positive impact on the time, cost, and quality of the entire engineering and construction process, as well as on the life cycle performance of constructed facilities. This could include qualification fo process equipment and/or additional certification requirements.
Realistic tolerances for construction e.g. concrete wall thickness	Perform owner acceptance reviews of all design deliverables.
Potential adverse impact of the workforce on the local community-misconduct of any construction worker is likely to be a negative reflection on the company	Provide training and education in a leadership development program for leadership positions.
Scheduling Activities around Major Holidays, which cause labor shortages; sensitivity to culture	Provide training and education in a leadership development program for leadership positions.
Lack of QA inspectors	Develop a comprehensive plan to attract young people to the construction workforce and retain them in careers.
Inexperience of QC Inspectors	Guidelines to improve training composed of contractors, owners and educational institutions, while reinforcing a broader scope of inspection for quality assurance issues.
Inexperience of hired workers to work in the nuclear environment	Guidelines to improve training composed of contractors, owners and educational

	institutions.
Inexperienced concrete finishers and welders	Guidelines to improve craft training composed of contractors, owners and educational institutions.
Diversity of construction workers e.g. many of the construction workers are Hispanic and do not speak English	Guidelines to improve craft training composed of contractors, owners and educational institutions.
Perform Construction under an operating license, which results in design changes	Develop a comprehensive plan to attract young people to the construction workforce and retain them in careers.
25 companies working at the site were not communicating and coordinating activities well	Increase effective communication between companies using a communications project assessment tool.
Owner not part of the management team	Team building between the owner, designer, and/or contractor. Owner needs to be engaged in design, procurement, and construction.
Keep construction on the critical path	Frequent advance review of the schedule to identify regulatory, design, and procurement activity challenges.
Identify all required permits and permitting schedules	Address possible differences in industry codes and standards editions and addenda required to meet both state and federal requirements.
Personal cell phones affecting safety and productivity	Setting and communicating safety performance expectation of "zero" lost time injuries expectation to employees.

Table 4 Best Practices for Nuclear Power Plant Projects

5. Conclusions

Problems are prevalent in the construction industry and have caused major issues in past nuclear construction projects in regards to schedule and cost. This study presents the increasing demand for electricity and the need of nuclear power generated electricity. Further information provides an in-depth look at the root causes of nuclear project problems and/or issues, correlating to cost and schedule overruns, which in extreme cases have been the sources for nuclear project shutdowns affecting the construction industry as a whole. The research offered reiterates known causes faced during nuclear project construction phases. In this study, 9 nuclear power plants and one U.S. fuel enrichment facility were examined to help identify root causes and develop best practices that can only be implemented in nuclear power plant construction projects.

In the findings of this research, the three most common knowledge structure issues among the projects were identified based on most occurrences:

- Best Practice Codes B: Design – 7 Occurrences
- Best Practice Codes C: Procurement – 20 Occurrences
- Best Practice Codes F: People – 28 Occurrences

All three issues identified are considered to be the top three main issues in nuclear construction today. Each contributes a major factor in affecting the construction process, overall having an impact on project budget, schedule, quality, and performance. Table 5 is a summary of knowledge structure findings from each project. In addition, Figure 3 serves as a visual aid for the project totals. As been previously discussed above and can be seen from Figure 3, knowledge structure codes B, C, and F occurred most frequently.

Project	Best Practice Codes												Total
	A	B	C	D	E	F	G	H	I	J	K	L	
Project 1	0	1	5	1	0	8	3	0	2	0	1	0	21
Project 2	0	0	5	3	0	8	0	2	2	0	0	0	20
Project 3	0	2	2	0	1	4	0	0	1	0	1	1	12
Project 4	0	1	1	1	0	2	1	0	0	0	0	2	8
Project 5	1	1	4	0	0	3	1	0	0	0	1	0	11
Project 6	0	2	3	0	0	3	1	0	1	0	0	1	11
Project Total	1	7	20	5	1	28	6	2	6	0	3	4	83

Table 5 Knowledge Structure Project Totals Summary

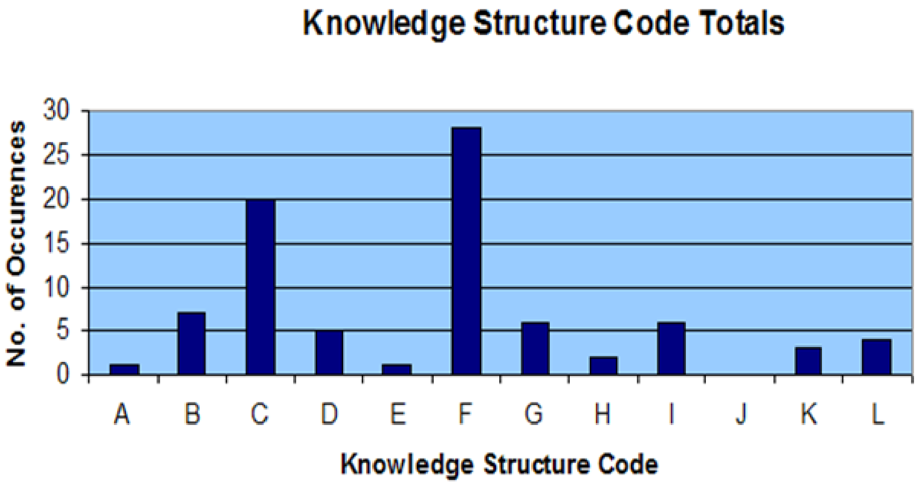

Figure 3 Knowledge Structure Project Totals Bar Chart

Best practices have been provided for each root cause problem and/or issue identified in each of the nuclear construction projects. Each root cause has its own significance and impact toward project cost and schedule. It is the owner and/or contractors responsibility to weight, rank, and categorize the importance of each root cause. In addition, implementation of the best practices based on necessary needs is essential and a duty of the owner or contractor for improving project budget, schedule, quality, and performance. With anticipation, this study should help owners gain an in-depth understanding of project problems and issues, overall mitigating project risk and uncertainty through implementing a set of best practices as a proactive effort. In order to achieve the desired results of minimization, it will take corporate commitment and dedication.

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